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Heterosis in pearl millet for yield and yield attributing characters

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Abstract
The experimental material comprised of thirty two crosses along with twelve parents (four lines and eight testers) and standard checks AHB 1200 Fe and AHB 1269. The experiment was laid out in Randomized Block Design with two replications. The observations were recorded on ten characters viz., days to 50 percent flowering, days to maturity, plant height, number of effective tillers, earhead length, earhead head girth, Fe Content, Zn Content, 1000 grain weight, grain yield and fodder yield. The analysis of variance revealed that there were significant differences among the parents and crosses for all the characters studied. Considering the heterosis 94555A x 15815R, 92444A x 15706R, 92444A x 16656R and 98222A x 16531R appeared to be the more promising hybrids for breeding.

Keywords: Pearl millet, bajra, cat tail, spiked or bulrush millet, heterosis

Introduction
Pearl millet, also known as bajra (*Pennisetum glaucum* (L.) R. Br.), ranks as the world's sixth and India's fourth most important cereal crop, following rice, wheat, and maize. Commonly referred to as pearl millet, cat tail, spiked millet, bulrush millet, or cumbu, it is known as bajra or bajari in various parts of the world. This crop belongs to the family Poaceae (Gramineae), subfamily Panicoideae, with a chromosome number of 2n=14. It falls under the genus Pennisetum and species glaucum, among others. Pearl millet is a highly cross-pollinated crop characterized by protogynous flowering (where the pistil matures before the stamens) and a wind-borne pollination mechanism, meeting a key biological requirement for hybrid development programs.

Pearl millet exhibits a balanced genetic load but experiences substantial inbreeding depression (Harinarayana, 1980) [7]. Therefore, varieties developed for pearl millet are preferred to be heterozygous for heterosis and homozygous for synchronous and stable production. Consequently, breeding efforts focus on developing hybrids, synthetic varieties, and composite populations. A major productivity breakthrough in pearl millet—from 303 kg/ha to 850 kg/ha—was achieved primarily through hybrid production using the cytoplasmic genetic male sterility (CGMS) system. The first discovery of the Tift 23A cytoplasmic male sterile line by Burton in 1958 in Tifton, Georgia, USA, paved the way for hybrid seed development in pearl millet. India's first pearl millet hybrid, HB-1, was released in 1965 (Athwal, 1965) [3], followed by several other promising hybrids, including HB-2, HB-3, HB-4, and HB-5, which have been widely adopted for cultivation. Recognizing the need for additional sources of male sterility, research identified multiple alternative sources such as A1, A2, A3, A4, A5, and others. The present study was thus conducted to estimate the nature and extent of heterosis for yield and its components in pearl millet.

Materials and Methods
The parental materials consisting of 4 male sterile lines used as female, 8 inbreds or tester used as male and 2 checks were used and obtained from National Agricultural Research Project (NARP), Aurangabad. The crosses were done in line x tester fashion during Kharif 2023.

The following important parents are used in the crossing programme and cross produced for the studies in pearl millet.

Parents Female (A line)
1. 92444A
2. 95111A
3. 94555A
4. 98222A

Male (R line)
1. 16656R
2. 17052R
3. 15025R
4. 15603R
5. 15734R
6. 15706R
7. 15815R
8. 16531R

Checks
1. AHB 1200 Fe
2. AHB 1269

The crossing program to obtain hybrid or crossed seed was conducted during the Kharif season of 2023 at the National Agricultural Research Project (NARP) fields in Aurangabad. Four male-sterile lines (females) were crossed with eight inbreds (males) following a line × tester design (4 × 8 = 32 crosses). The resulting crossed seeds were used as F1 or hybrid seed in the present research. The experiment followed a Randomized Block Design (RBD) with two replications. A total of 46 treatments were included, consisting of 32 F1s, 4 female lines, 8 male parents, and 2 checks.
The parent and hybrids were planted in a plot of 1 row of 4.0 m length having a row to row spacing 45 cm and 15 cm plant to plant. In order to ascertain or study the combining ability, parents were also included in the same set and analysis of the data was done.
In order to ascertain or study the heterosis, parents were also included in the same set and analysis of the data was done. In the form of modified line x tester design as suggested by Arunachalam (1974) [2]. Mean data were used for statistical analysis. The degree of heterosis in F1 over mid parent (Jinks, 1983) [9] and better parent (Turner, 1953) [13] was calculated for individual character and expressed in percent.

Results and Discussion
Heterosis is the measure of superiority of hybrid over parental means. Heterosis may be either positive or negative, depending on the magnitude of hybrid means. Parent vs hybrids interaction mean sum of squares provide a measure of heterosis. In the present investigation parent v/s hybrids interaction mean sum of squares were significant for all the traits. But such comparison will test the difference between parental and hybrid group means. The significant differences could arise due to a few but highly heterotic combinations hence, analysis of heterosis based on single hybrids or between two lines or two populations, which have no common origin, has its importance (Falconer, 1981) [6].
For days to 50 percent flowering, the hybrid 94555A x 15603R recorded the higher magnitude of heterosis in desired direction over the standard hybrid check AHB 1200 Fe and the hybrid 92444A x 15706R shown higher magnitude of heterosis in desired direction over the standard hybrid check AHB 1269 Fe. Similar results were reported by earlier workers Chavan and Nerkar (1994) [5] and Pachade (2006) [10].
The hybrids showing higher magnitude of heterosis over standard check AHB 1200 Fe in desirable direction for days to maturity was 98222A x 15815R. Similar results were observed by Rafiq *et al*. (2016) [11].
For plant height, the hybrid 98222A x 15706R recorded the higher magnitude of heterosis in desired direction over better parent. Similar results for plant height has also been reported by Sheoran *et al*. (2000) [12].
The Effective tillers per plant is one of the important yield attributes and positive heterosis is desirable. The hybrid, 95111A x 15706R and 98222A x 15706R displayed higher positive heterosis over standatd check AHB 1200 Fe and better parent. Similar type of reports were reported by Kapadiya *et al*., (2016) [8].
For earhead length, hybrid 94555A x 15025R showed higher heterosis over standard hybrid check AHB 1200 Fe. The coss 92444A x 16656R showed higher heterosis over better parent. The present result reported were in agreement with those of Chavan and Nerkar (1994) [5] and Pachade (2006) [10]
The responce of the hybrids for earhead girth, highest significant heterosis was exhibited by the cross 94555A x 15025R for better parents. In previous studies M. Vetriventhan, *et al*., (2008) [14] reported positive heterosis for earhead girth.
The highest significant heterobeltiosis and mid parent heterosis was exhibited by the cross 92444A x 16656 for 1000 grain weight. Previously Alidad Amiribehzadi, *et al* (2012) [15] observed similar result of heterosis for 1000 grain weight.
The highest heterosis for grain yield per plant was displayed by 94555A x 15815R, over the mid parent and 92444A x 17052R over the better parent.
Highest standard heterosis for fodder yield per plant was observed in case of 92444A x 15706R. Whereas, some hybrids showed significantly positive standard heterosis for this trait.
The highest heterosis for Fe content was displayed by 98222A x 17052R, over the mid parent and 98222A x 17052R over the better parent.
For Zn content, hybrid 95111A x 16531R showed higher heterosis over mid parent and hybrid 92444A x 16531R showed higher heterosis over better parent. However, hybrid 94555A x 15706R was found most heterotic over standerd hybrid check AHB 1200Fe.

Table 1: Analysis of the variance for different characters in L x T mating design in pearl millet.

Source	D.F.	Days to 50% flowering	Days to maturity	Plant height	No. of effective tillers/Plant	Ear head length	Ear head girth	1000 grain weight	Grain yield/Plant	Fodder yield/plant	Fe content (%)	Zn content (%)
Replications	1	7.56	1.00	0.90	0.001	5.00	0.001	0.11	8.70	7.49	0.01	0.11
Treatments	43	27.01**	77.77**	545.01**	0.07**	16.24**	0.37**	8.77**	26.20**	49.03*	237.58**	23.02**
Error	43	2.62	1.48	86.73	0.02	1.28	0.02	0.26	3.26	19.01	0.24	0.14

*, ** denote significant at 5% and 1 % levels, respectively.

Sr. No.	Hybrids	1. Days to maturity			
		M.P. (%)	B.P. (%)	Standard hybrid Checks	
				AHB 1200 Fe	AHB 1269
1	92444A X 15025R	-14.36**	-15.30**	-13.89**	-14.84**
2	94555A X 15025R	-14.91**	-15.59**	-12.78**	-13.74**
3	94555A X 15603R	-14.44**	-17.20**	-14.44**	-15.38**
4	98222A X 15815R	-12.68**	-14.45**	-17.78**	-18.68**
5	92444A X 15603R	-12.75**	-13.97**	-14.44**	-15.38**

Sr. No.	Hybrids	2. Plant height			
		M.P. (%)	B.P. (%)	Standard hybrid Checks	
				AHB 1200 Fe	AHB 1269
1	98222A X 15706R	-16.13**	-19.75**	-20.69**	-21.32**
2	92444A X 15603R	-14.23**	-17.71**	-23.61**	-24.21**
3	94555A X 15603R	-13.09**	-15.55**	-23.63**	-24.24**
4	98222A X 15025R	-12.87**	-18.09**	-19.05**	-19.68**
5	95111A X 16531R	-7.28	-11.02*	-21.83**	-22.45**

Sr. No.	Hybrids	3. No. of effective tillers/plant			
		M.P. (%)	B.P. (%)	Standard hybrid Checks	
				AHB 1200 Fe	AHB 1269
1	95111A X 15706R	61.76**	27.92**	22.22**	17.02**
2	94555A X 16531R	50.72**	23.81*	15.56*	10.64
3	95111A X 16531R	46.27**	16.67*	8.89	4.26
4	95111A X 17052R	45.45**	17.07*	6.67	2.13
5	92444A X 16531R	42.47**	23.81**	15.56*	10.64

Sr. No.	Hybrids	4. Ear head length			
		M.P. (%)	B.P. (%)	Standard hybrid Checks	
				AHB 1200 Fe	AHB 1269
1	92444A X 16656R	39.29**	29.21**	4.34	28.60
2	95111A X 16656R	33.33**	32.24	-8.68	12.56
3	94555A X 15025R	32.58**	31.75**	-0.57	22.56
4	94555A X 16656R	27.42**	22.00**	-7.92	13.49
5	92444A X 15025R	25.64**	20.79**	-2.45	20.23

Sr. No.	Hybrids	5. Ear head girth			
		M.P. (%)	B.P. (%)	Standard hybrid Checks	
				AHB 1200 Fe	AHB 1269
1	94555A X 15025R	41.94**	34.69**	-5.71	-4.35
2	98222A X 16656R	28.85**	24.07**	-4.29	-2.90
3	92444A X 16656R	11.67**	-4.29	-4.29	-2.90
4	94555A X 17052R	12.87*	9.62	-18.57**	-17.39**
5	92444A X 15734R	13.79**	-5.71	-5.71	-4.35

Sr. No.	Hybrids	6. 1000 grain weight			
		M.P. (%)	B.P. (%)	Standard hybrid Checks	
				AHB 1200 Fe	AHB 1269
1	92444A X 16656R	62.00**	53.80**	8.97	4.74
2	92444A X 15025R	54.66**	38.33**	11.66*	7.33
3	95111A X 16656R	48.96**	40.22**	12.56*	8.19
4	92444A X 15603R	41.14**	28.16**	0.00	-3.88
5	95111A X 15603R	33.14**	31.28**	5.38	1.29

Sr. No.	Hybrids	7. Grain yield/plant			
		M.P. (%)	B.P. (%)	Standard hybrid Checks	
				AHB 1200 Fe	AHB 1269
1	92444A X 16656R	5.20	0.48	1.08	6.07
2	94555A X 15815R	13.75*	9.20	-1.33	3.54
3	98222A X 15815R	11.56	5.13	-1.20	3.67
4	98222A X 16656R	6.36	5.00	-1.33	3.54
5	94555A X 16531R	5.73	1.22	0.00	4.93

Sr. No.	Hybrids	8. Fodder yield per plant			
		M.P. (%)	B.P. (%)	Standard hybrid Checks	
				AHB 1200 Fe	AHB 1269
1	92444A X 15706R	16.56*	11.39	7.32	15.79*
2	92444A X 16531R	15.16*	8.02	4.07	12.28
3	98222A X 15025R	15.44*	12.53	-9.43	-2.28
4	95111A X 15025R	10.86	-2.65	-1.63	6.14
5	94555A X 15025R	9.20	3.02	-11.22	-4.21

Sr. No.	Hybrids	9. Fe content			
		M.P. (%)	B.P. (%)	Standard hybrid Checks	
				AHB 1200 Fe	AHB 1269
1	98222A X 17052R	66.22**	62.08**	0.62	-0.50
2	95111A X 17052R	39.88**	23.24**	0.39	-0.72
3	94555A X 15025R	38.25**	29.52**	-2.13*	-3.22**
4	95111A X 15025R	37.22**	24.21**	1.18	0.06
5	92444A X 15025R	10.37**	-7.29**	-10.00**	-11.00**

Sr. No.	Hybrids	10. Zn content			
		M.P. (%)	B.P. (%)	Standard hybrid Checks	
				AHB 1200 Fe	AHB 1269
1	95111A X 16531R	45.77**	25.45**	2.60**	-0.24
2	92444A X 16531R	30.53**	26.97**	3.84**	0.96
3	98222A X 16531R	30.60**	25.45**	2.60**	-0.24
4	95111A X 16656R	26.38**	-0.48	2.11*	-0.72
5	95111A X 15706R	28.58**	2.50*	1.73	-1.08

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